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Observations of AGN with the First VERITAS Telescope

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The first VERITAS (Very Energetic Radiation Imaging Telescope Array System) telescope has been in operation at the basecamp of the Whipple Observatory since January 2005. Here we present initial observations of AGN made using this telescope. Although this is engineering data, significant detections of Markarian 421 and Markarian 501 have been achieved.

1. Introduction

During the first 5 months of 2005, the first VERITAS Telescope was operated as a stand-alone Imaging Atmospheric Cherenkov Telescope (IACT) at the basecamp of the Whipple Observatory in southern Arizona. The Crab Nebula, which is regarded as the standard candle of TeV gamma-ray astronomy, was a priority target during this period. The detection of the Crab Nebula was announced with the First Light declaration on February 1st 2005 and is reported elsewhere [8].

Following this detection, observations of the Crab Nebula continued in conjunction with observations of established TeV emitters such as Markarian 421 and Markarian 501.

In this paper the scientific motivations for observing Active Galactic Nuclei with VERITAS will be outlined, the telescope will be briefly described and the preliminary analysis of the AGN data will be presented.

2. Scientific Motivation

The non-thermal emission of Active Galactic Nuclei (AGN) is well characterised by a νF_ν plot [13]. This Spectral Energy Distribution (SED) shows two broad peaks; the lower ranges from the infrared to the x-ray whereas the higher peaks at gamma-ray energies. The lower energy peak is generally attributed to synchrotron emission by highly relativistic electrons within plasma jets which propagate perpendicularly away from the plane of the host galaxy [1]. There is less certainty regarding the origin of the higher energy peak and several plausible models exist. In the Inverse Compton (IC) model, high-energy emission is produced through inverse-Compton scattering of the relativistic electrons with either the locally produced synchrotron photons (Synchrotron Self Compton model) or with photons from the external environment (External Compton model). In a hadronic model, protons are shock accelerated in the jet to extremely high energies. These protons can collide with target nuclei in the jet and produce neutral pions which decay to high energy photons [10]. Alternatively high energy photons can be produced via proton-synchrotron emission. Only through observations of flux and spectral variability over a broad range of wavelengths can the emission mechanisms be determined.

An understanding of the extra-galactic background light (EBL) is necessary for studies of star and galaxy formation. However, measurement of the EBL in the optical to far infra red is inhibited by foreground radiation such as that due to diffuse dust in the Milky Way Galaxy. Very high energy (VHE) photons are absorbed by the EBL via pair production. For those AGN which have been detected, an attenuation of the spectral index with increasing red shift has been observed[12]. This can be interpreted as scattering of VHE photons off the EBL at higher energies. If the intrinsic AGN spectrum is known, information about the shape of the EBL spectrum

can be extracted and would shed new light on the evolution of the universe. Thus far there are 6 confirmed AGN which have contributed to an understanding of the EBL. In order to further constrain this background, a large catalog of AGN at various redshifts must be established. This will be a primary goal of VERITAS.

3. VERITAS Telescope 1

VERITAS Telescope 1 was operated as a stand-alone IACT instrument from January through June 2005 [8] following autumn upgrades to the VERITAS prototype [4]. The telescope is temporarily located at the base-camp of the Whipple Observatory. This is not at an optimal observing elevation and is not well shielded from background light pollution. The telescope uses the Davies Cotton [5] reflector design and has a focal length of 12m, making it an f/1 system for a 12m aperture. The telescope comprises 340 mirrors giving a surface area of 100 m^2. The telescope's camera has 499 PMTs with a field of view of $3.5°$, however light cones have not yet been installed.

VERITAS Telescope 1 utilises a two-level trigger system. Trigger level one consists of constant-fraction discriminators (CFDs) which discriminate against night-sky background [7]. The level-two trigger is a topological hardware trigger which can discriminate between compact Cherenkov events and random night-sky or afterpulse-induced events [2].

The PMT signals are digitised by a custom-designed 500 MHz flash-analogue-to-digital converter (FADC) system [3]. The data acquisition has 50 FADC boards, containing 10 channels each, located in four VME crates. For every event, the FADCs provide a pulse profile for each pixel. As well as improving the signal to noise ratio, reducing the need for delay cables and reducing deadtime, the FADCs may provide a new technique for discriminating against hadronic events by using the pulse profiles to study the temporal evolution of the extensive air shower [8].

4. Observations/Analysis

All observations were taken in PAIR mode where the source is observed for 28 minutes (ON), followed two minutes later by a similar exposure (OFF) with an offset of 30 minutes in Right Ascension (RA) in order to assess the background. For this dataset, the analysis was tested and optimised using observations of the Crab Nebula [8].

Charges are derived from the FADC traces by integrating over a window that is centered on the FADC trace and set in a two pass optimised filter [8] to maximise the signal to noise ratio (Figure 1). After identification of dead channels, subtraction of pedestals and relative gain correction, images are prepared for parameterisation using picture/boundary cleaning [6] with cuts on the charge of 4.0 (picture) and 2.0 (boundary) times the pedestal RMS. Standard image parameterisation [6] is implemented and cuts, optimised on observations taken on the Crab Nebula, are applied. Distributions of the image parameter alpha [6], are shown in Figure 2 for Markarian 421 and Markarian 501. For point sources located at the center of the field of view, the alpha distribution should peak at low values. In each case, the alpha distribution (after application of cuts [9]) for the ON source field is shown with the OFF field overlayed. Two dimensional significance maps, smoothed with a simple boxcar algorithm, are presented in Figure 3. Observations of Markarian 421 yielded a 12.5σ detection over 13.1 hours, whereas observations of Markarian 501 yielded a 7.1σ detection over 6.7 hours. Finally, light curves are shown in Figure 4 with Whipple 10m data points for comparison. The Whipple 10m data were taken within, at most, one hour of the VERITAS Telescope 1 data. Also shown are ASM/RXTE[11] quicklook daily averages.

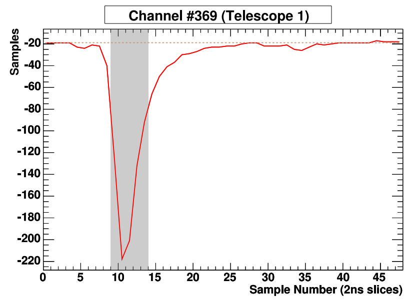

Figure 1. FADC trace from a laser pulse. The optimised summation window is indicated by the shaded area and the pedestal is indicated by the dashed line. Sampling is performed at intervals of two nanoseconds.

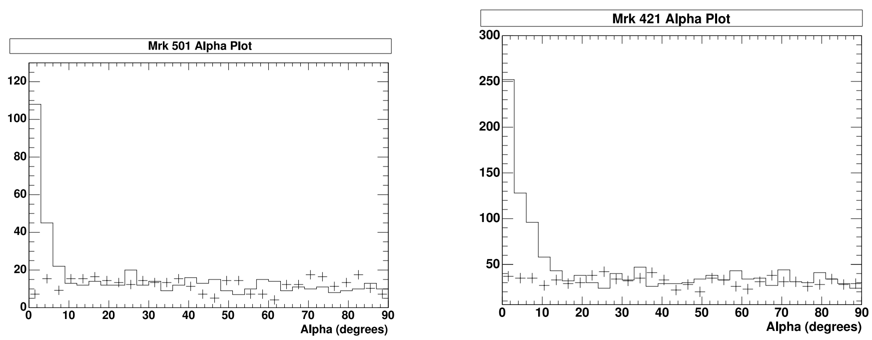

Figure 2. *Left:* Alpha distribution for Markarian 501. *Right:* Alpha distribution for Markarian 421. The ON source distribution is represented by the solid line, with the OFF source distribution represented as crosses.

5. Conclusions

VERITAS Telescope 1 operated at a temporary location at the basecamp of the Whipple Observatory from January to May 2005. During this engineering period, the Telescope successfully detected the Crab Nebula, Markarian 421 and Markarian 501. The telescope performed well without light cones in an area with significant background light, at a comparatively low elevation and with analysis that was not fully optimised. Despite these factors and the short period of operation, Telescope 1 met all (and exceeded many) expectations and proved to be a superior instrument to the Whipple 10m Telescope.

The VERITAS Collaboration is currently constructing a second identical telescope at the basecamp of the Whipple Observatory. As well testing the array trigger and improving background rejection, this configuration will significantly reduce the energy threshold by suppressing triggers on local muons.

6. Acknowledgments

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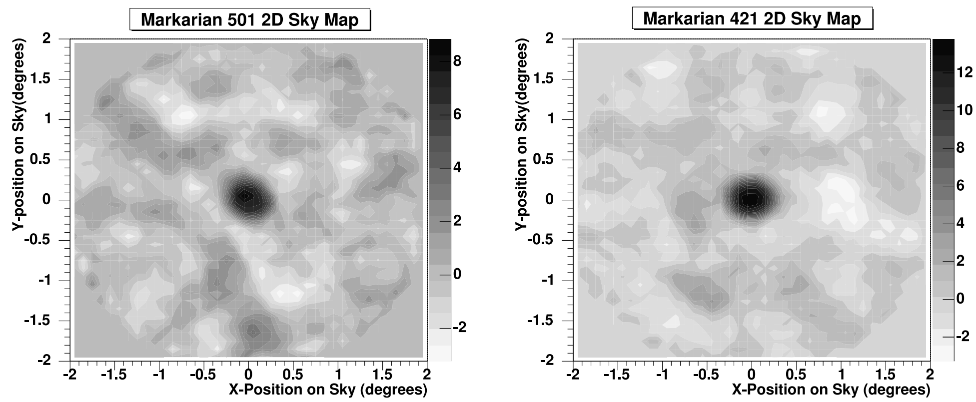

Figure 3. *Left:* Two-dimensional significance map for Markarian 501. *Right:* Two-dimensional significance map for Markarian 421. The colour scale refers to significance levels (note different scales). Adjacent bins are not independent.

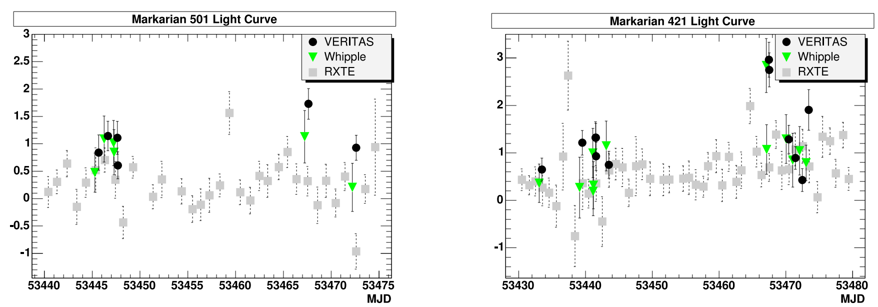

Figure 4. *Left:* Light curve for Markarian 501. *Right:* Light Curve for Markarian 421. VERITAS/Whipple points are in γ/min and RXTE ASM points are in counts/sec.

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